BEHAVIOUR OF SOME PRIMARY CATALYSTS IN AIR-STEAM GASIFICATION OF SEWAGE SLUDGE

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INTEREST AND OPPORTUNITY OF THIS TECHNOLOGY

- **Sewage sludge (SS)**: liquid or semi-liquid waste generated in wastewater treatment plants

population increase + strict quality standards
Directive 98/15/EC

→ SS production increasing

Land use
Directive 86/278/EC

Landfilling
Directive 99/31/EC

Incineration
Directive 2000/76/EC

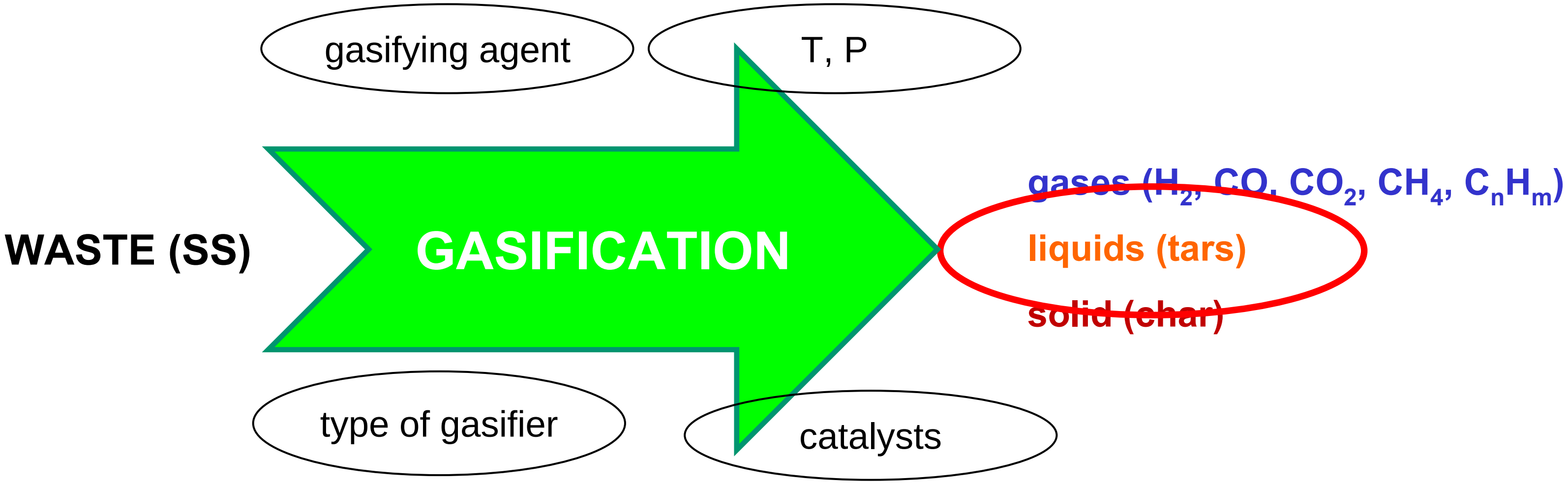
ALTERNATIVE

GASIFICATION

→ waste minimization and stabilization

→ valuable products (gases, adsorbents, energy)

→ emissions reduction



Combustion	$C + O_2 \rightarrow CO_2$	$\Delta H^o = -393{,}8$ kJ/mol
Incomplete combustion	$C + 1/2\,O_2 \rightarrow CO$	$\Delta H^o = -123{,}1$ kJ/mol
Methanation	$C + 2H_2 \rightarrow CH_4$	$\Delta H^o = -87{,}5$ kJ/mol
Water-gas shift	$CO + H_2O \rightarrow H_2 + CO_2$	$\Delta H^o = -40{,}9$ kJ/mol
Boudouard	$C + CO_2 \rightarrow 2CO$	$\Delta H^o = 159{,}9$ kJ/mol
Water-gas	$C + H_2O \rightarrow H_2 + CO$	$\Delta H^o = 118{,}5$ kJ/mol
Steam reforming	$C_nH_m + nH_2O \rightarrow nCO + (n + m/2)H_2$	$\Delta H^o > 0$
CO_2 reforming	$C_nH_m + nCO_2 \rightarrow (2n)CO + (m/2)H_2$	$\Delta H^o > 0$

DIAGRAM OF THE LABORATORY SCALE PLANT

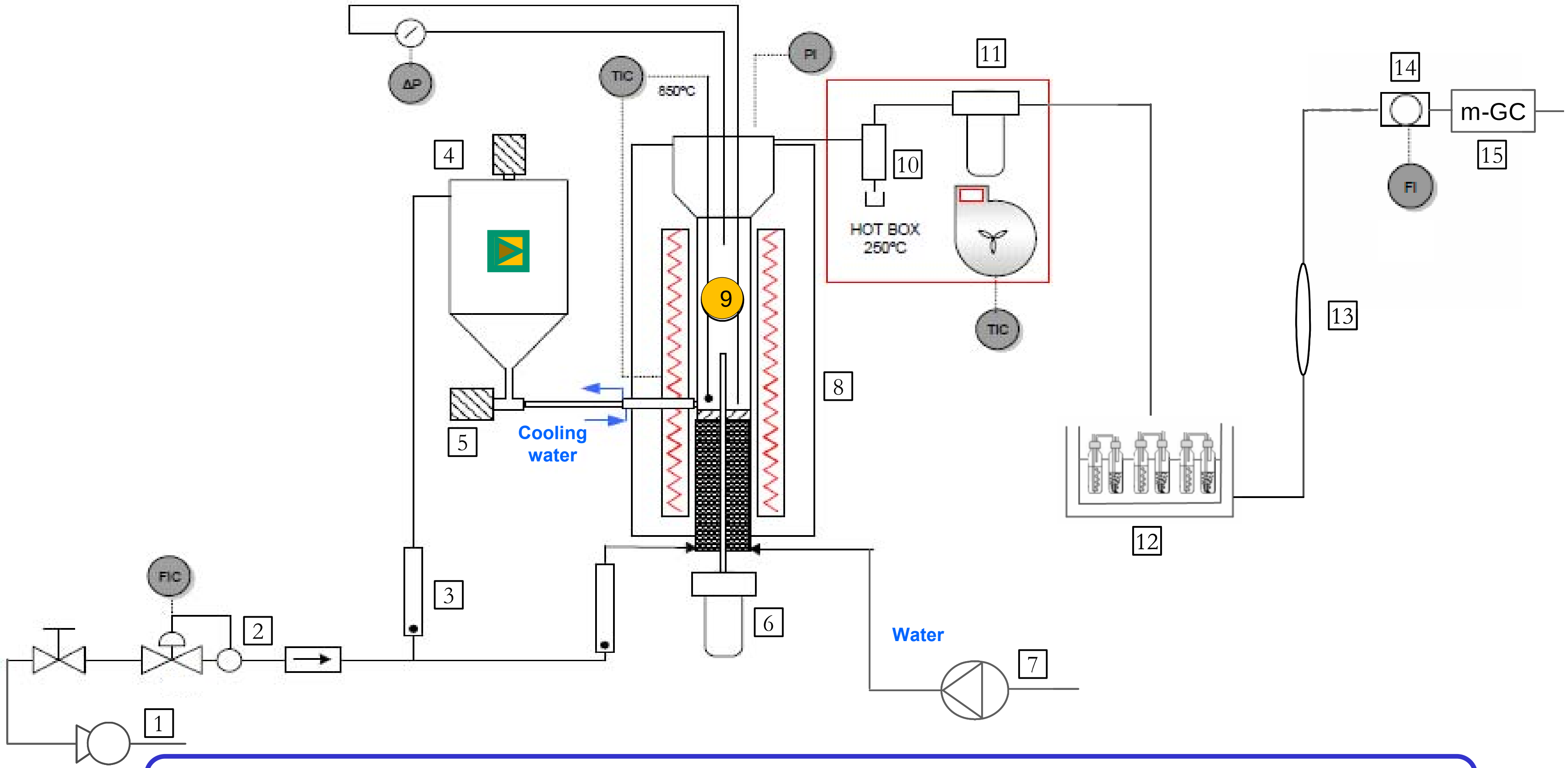


Diagram: 1. compressor; 2. mass flow controller; 3. rotameter; 4. feed hopper; 5. screw feeder; 6. ash hopper; 7. peristaltic pump; 8. furnace; 9. reactor; 10. cyclone; 11. hot filter; 12. condensation train; 13. water filters, silica gel and cotton; 14. mass flow meter; 15. micro gas-chromatograph

TESTS CARRIED OUT

Reference gasification conditions

- T (ºC) = 750 (1023 K) – 850 (1123 K)
- ER = 0.2 – 0.3 – 0.4
- S/B = 0 – 0.5 – 1

- T (ºC) = 750 (1023 K) – 850 (1123 K)
- ER = 0.3
- S/B = 0
- 10% – 15% catalyst in bed

Influence of catalysts in the bed

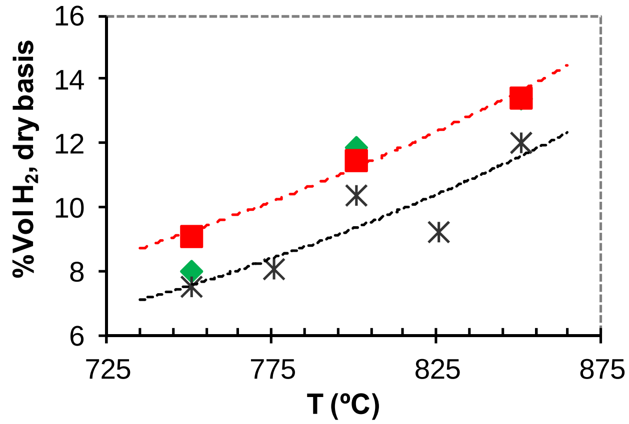
- olivine
- alumina
- dolomite

- T (ºC) = 800 (1073 K)
- ER = 0.3
- S/B = 0.5 – 1
- 10% catalyst in bed

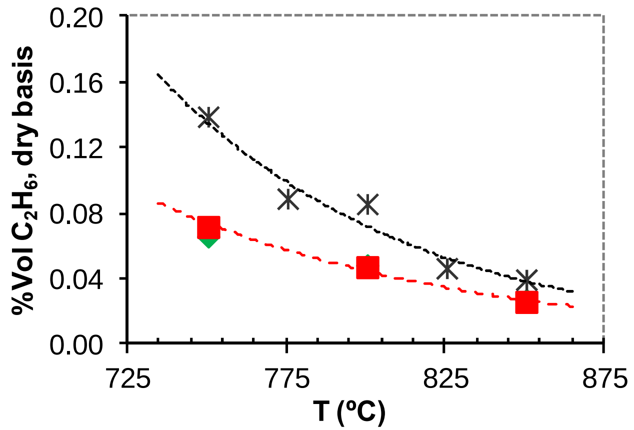
Influence of catalysts + steam

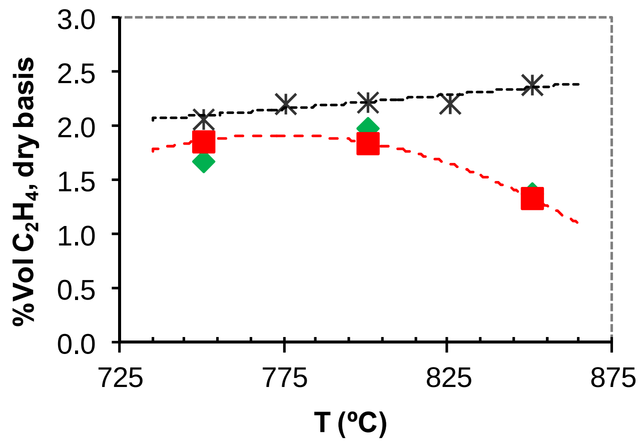
GASIFICATION RESULTS WITH CATALYST AND AIR

OLIVINE effect in gas composition



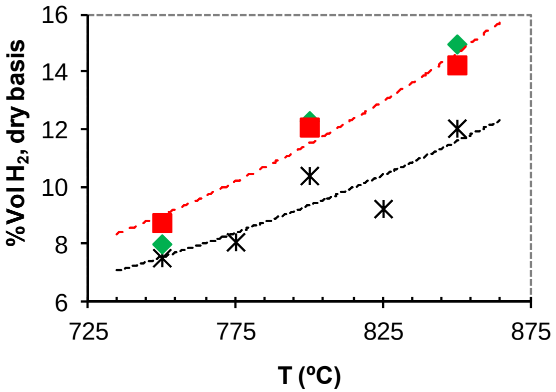
- Increase in H_2 and decrease C_nH_m content
- No relevant differences were found for the rest of the gases

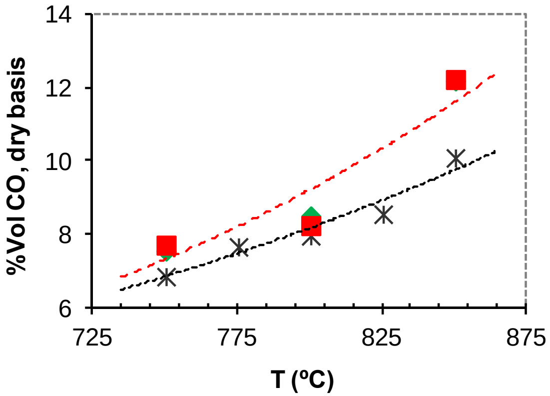




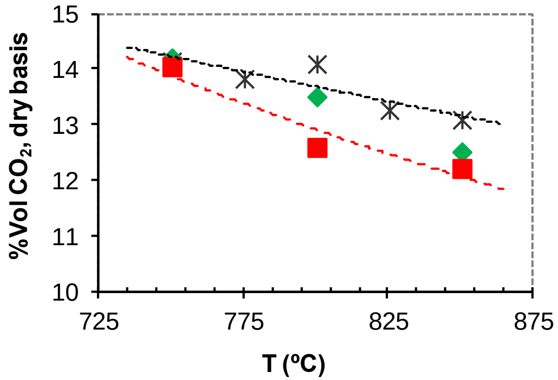
Gas composition according to the variation in temperature. Comparison between different amounts of olivine in the bed (ж no catalyst; ♦ 10% fed sludge; ■ 15% fed sludge)

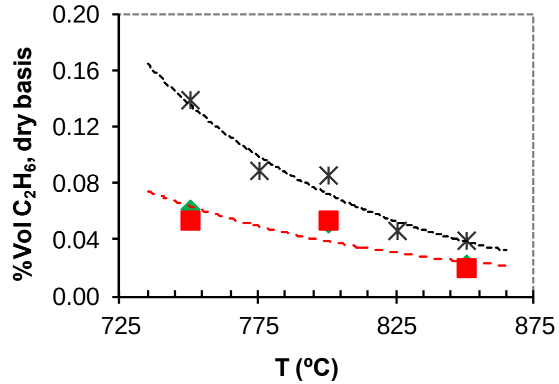
ALUMINA effect in gas composition





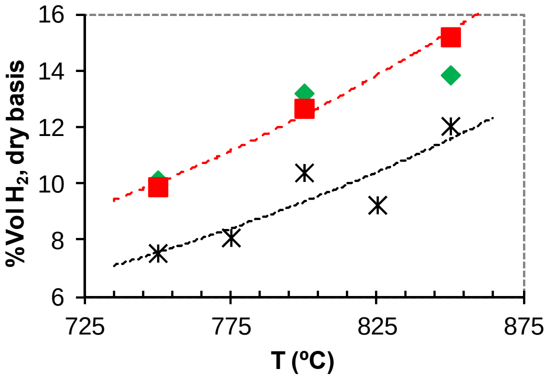
- Increase H_2 and CO
- Decrease CO_2, CH_4 and C_nH_m



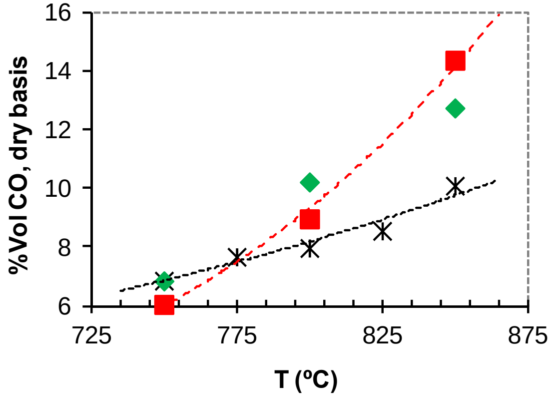


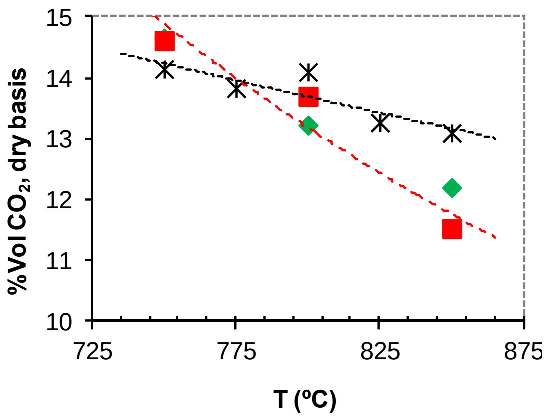
Gas composition according to the variation in temperature. Comparison between different amounts of alumina in the bed (ж no catalyst; ♦ 10% fed sludge; ■ 15% fed sludge)

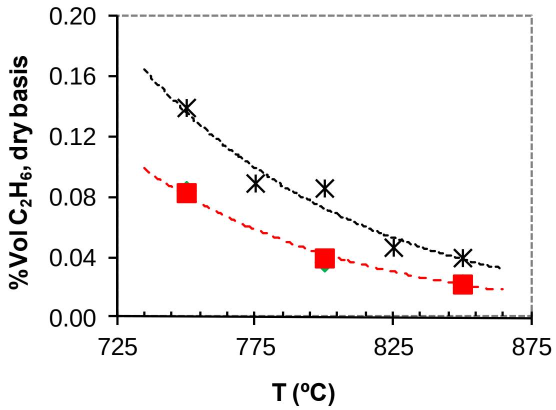
DOLOMITE effect in gas composition



- DOLOMITE and ALUMINA produce similar effects in gas composition





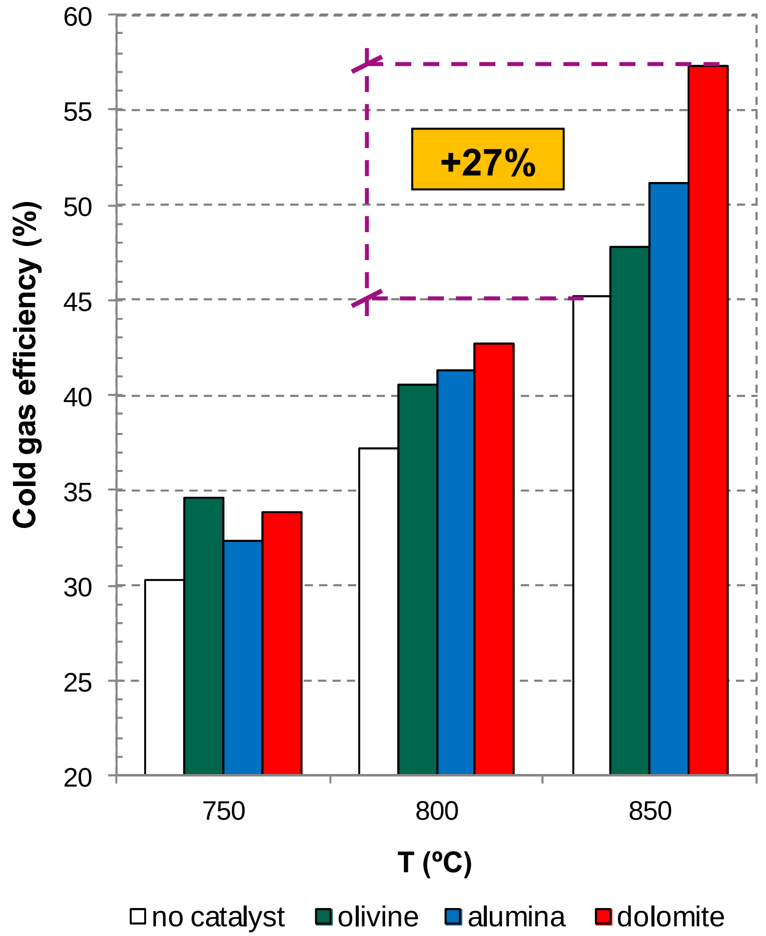


Gas composition according to the variation in temperature. Comparison between different amounts of dolomite in the bed (ж no catalyst; ♦ 10% fed sludge; ■ 15% fed sludge)

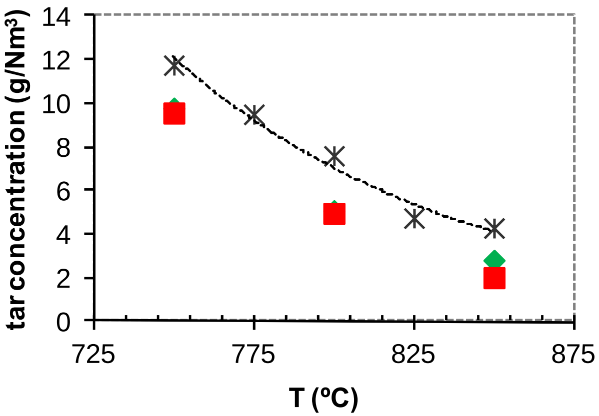
Effect of CATALYSTS in the "chemical energy" of the product gas (CGE)

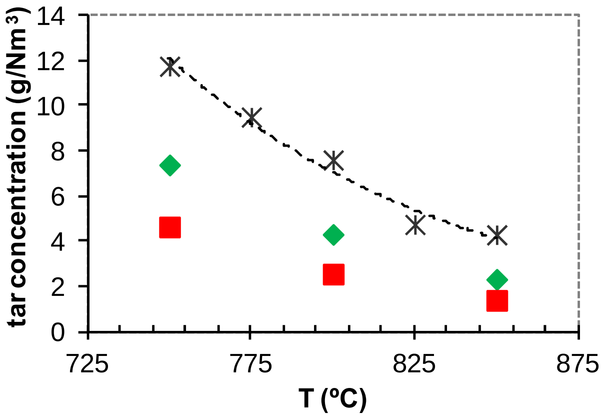
- ⬆ Y_{gas} → tars to permanent gases
- ⬆ LHV_{gas} → higher H_2 and CO content

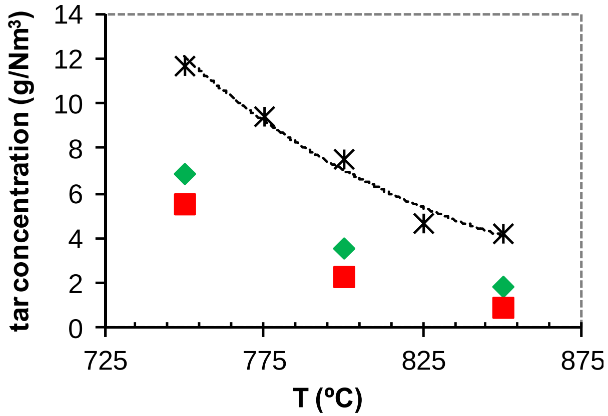
$$CGE\ (cold\ \ gas\ efficiency) = \frac{Y_{gas} \times LHV_{gas}}{LHV_{SS}}$$



Effect of CATALYSTS in "tar" production





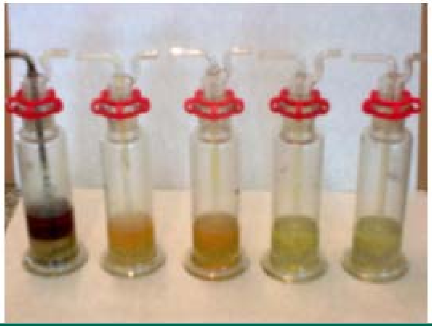
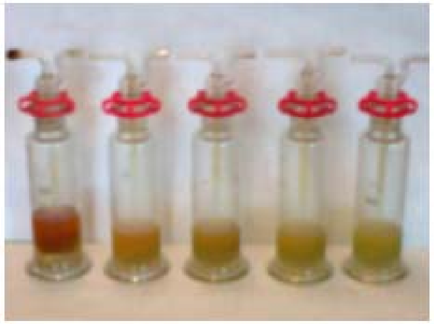
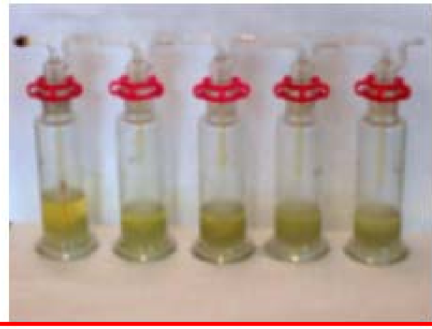


	Tar concentration reduction (%)	
	OLIVINE, % by weight in bed	
T (ºC)	10%	15%
750	-16.8	-18.6
800	-33.1	-34.7
850	-31.1	-50.5

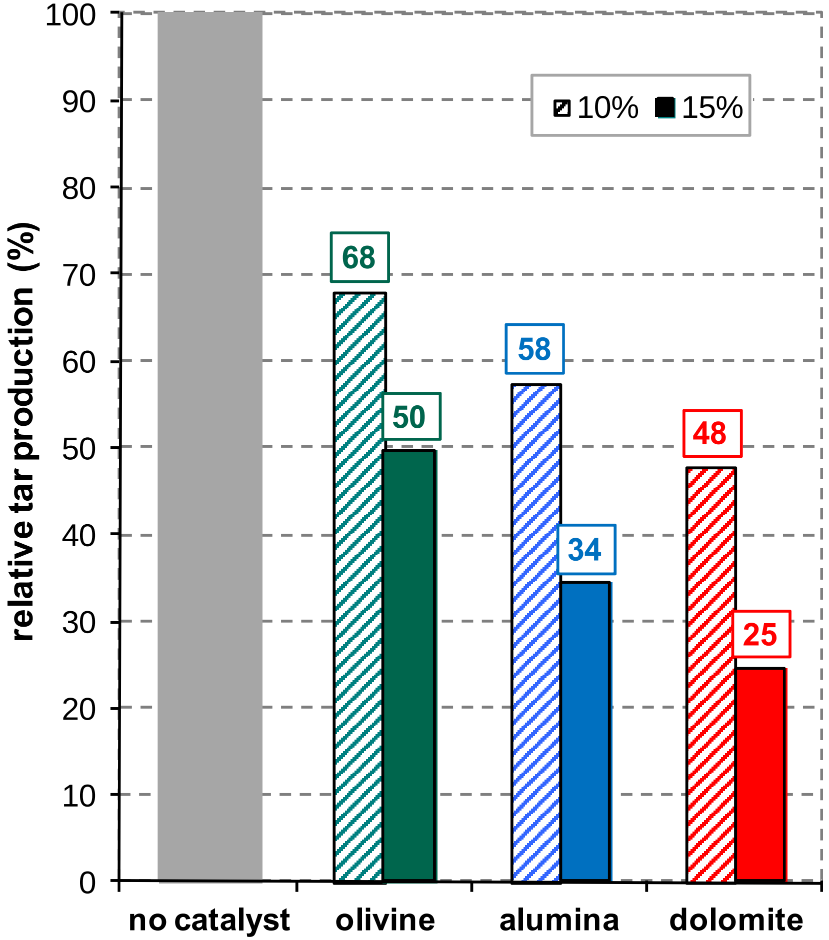
	Tar concentration reduction (%)	
	ALUMINA, % by weight in bed	
T (ºC)	10%	15%
750	-37.3	-60.2
800	-43.4	-65.8
850	-46.5	-67.4

	Tar concentration reduction (%)	
	DOLOMITE, % by weight in bed	
T (ºC)	10%	15%
750	-40.7	-52.5
800	-52.6	-68.4
850	-55.8	-76.7

Tar production and tar concentration. Comparison between different amounts of catalyst in the bed
(ж no catalyst; ♦ 10% fed sludge; ■ 15% fed sludge)

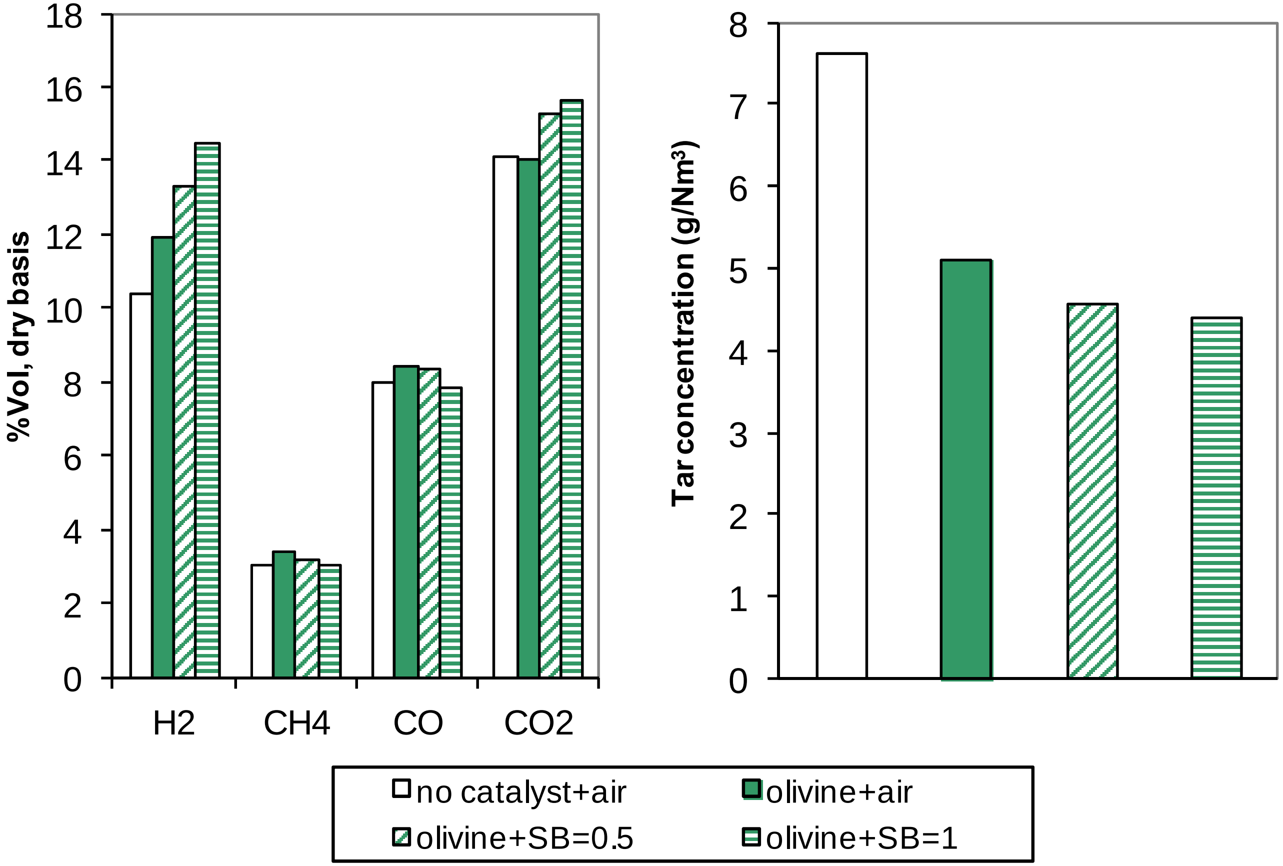
	750 ºC	850 ºC
OLIVINE		
ALUMINA		
DOLOMITE		

Comparative between catalysts (tar production 850ºC; ER = 0.3)



GASIFICATION RESULTS WITH CATALYST AND AIR-STEAM

OLIVINE+STEAM effect in gas composition and tar concentration



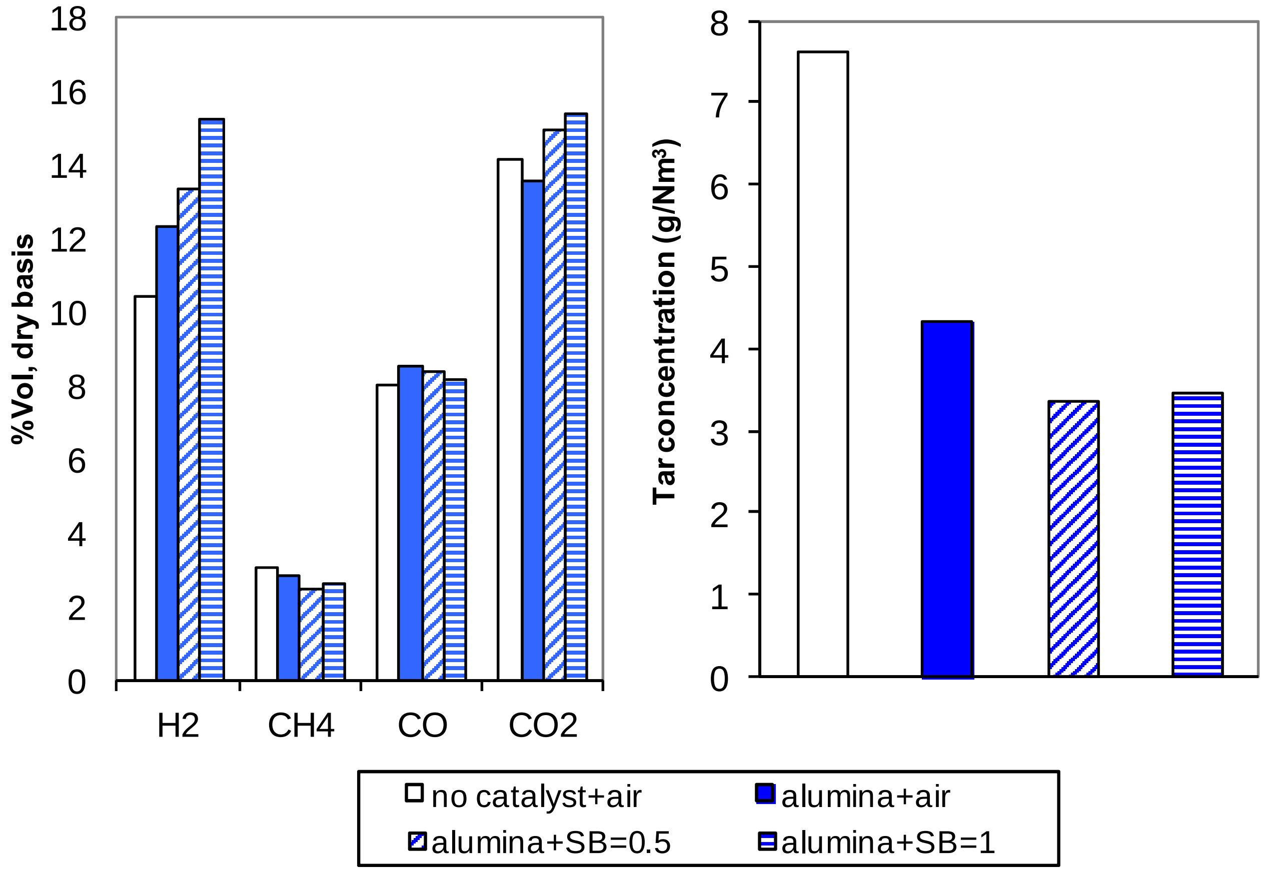
Adding steam

↑ H_2 and CO_2 ↓ CO

(water-gas shift)

Additional reduction of tar concentration via steam reforming

ALUMINA+STEAM effect in gas composition and tar concentration



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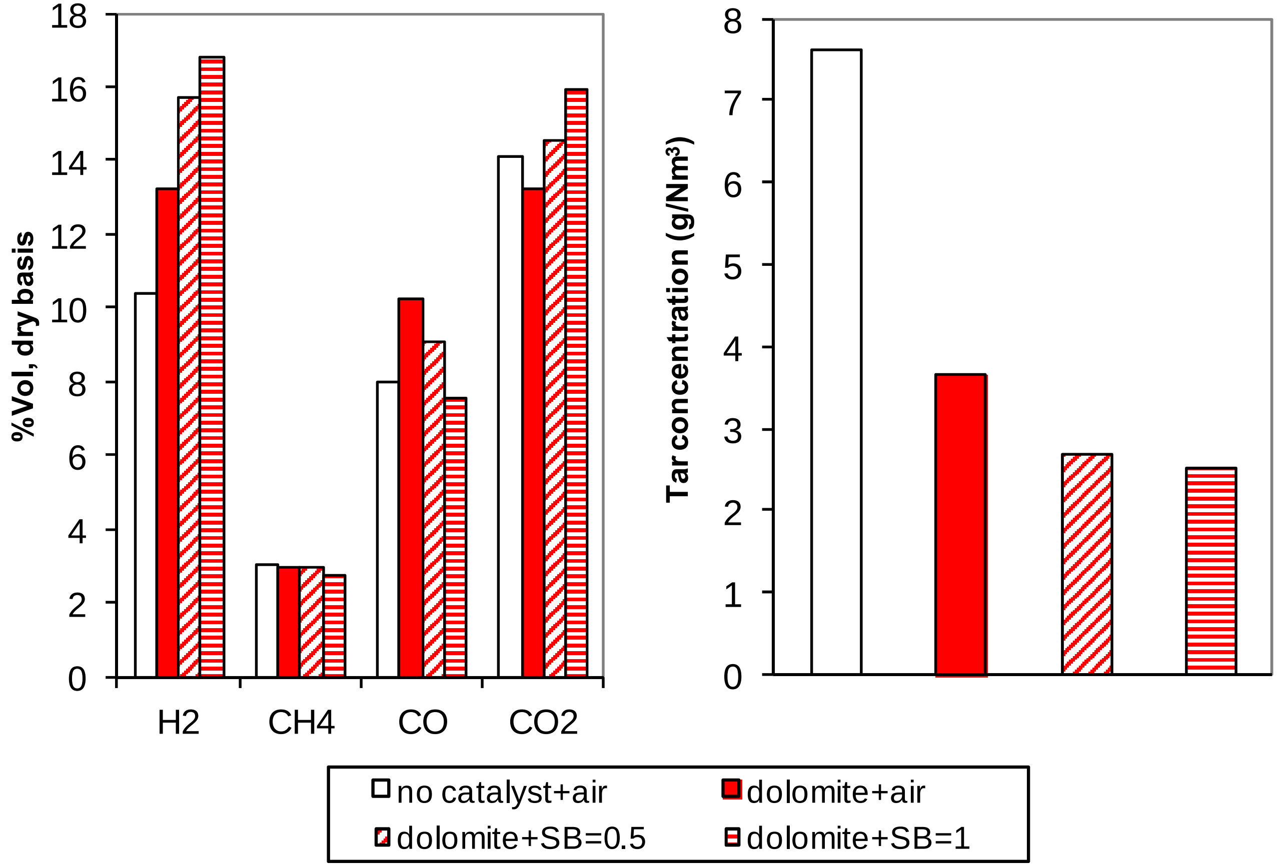
DOLOMITE+STEAM effect in gas composition and tar concentration



Adding steam

↑ H_2 and CO_2 ↓ CO
(water-gas shift)

Additional reduction of tar concentration via steam reforming

Main effects of CATALYST+STEAM in gasification products
T = 800ºC; S/B = 1

Catalyst	VARIATION RESPECT TO TESTS WITHOUT CATALYST AND AIR			H_2/CO
	H_2 content (%)	Tar production (%)	CGE (%)	
Olivine	+ 39.1	- 41.9	+ 20.7	**1.8**
Alumina	+ 46.0	- 54.5	+ 22.5	**1.9**
Dolomite	+ 61.3	- 66.6	+ 30.4	**2.2**

CONCLUSIONS AND FORTHCOMING STEPS

CONCLUSIONS

- Gasification is a suitable technology to convert sewage sludge into valuable products (electricity/heat, raw materials for chemical synthesis)

- Under optimized gasification conditions, gases with a low tar concentration (well bellow 1g/Nm^3) can be obtained with the use of primary catalysts in BFB

- Although both the olivine, alumina and dolomite are proved to be effective in tar reduction, the dolomite is the most active catalyst

- The combined use of catalyst and steam sharply increased H_2 content and made the SYNGAS more suitable for synthetic fuels and methanol production

FORTHCOMING STEPS

- Up-scaling the gasification plant. Test catalyst performance under more rough gasification conditions

- Study the applicability of the new results obtained to a wastewater treatment plant or to a sewage sludge drying plant. Determination of the level of electricity and heat own consumptions covered by SYNGAS use

THANKS FOR YOUR ATTENTION

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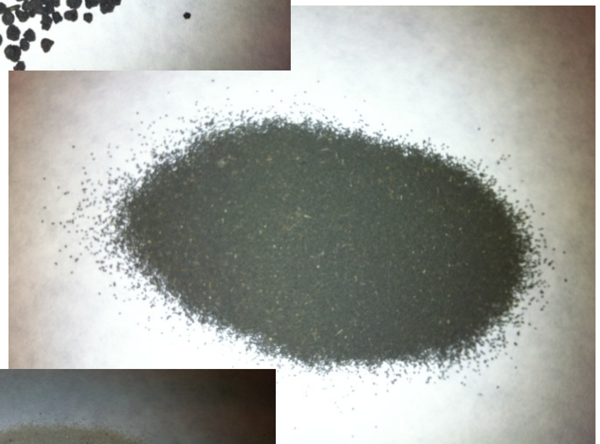
- Dried sewage sludge (2–5 mm ø)

-Sieved and crushed (300-500 µm)



- Moisture (%)	≈ 7.0
- Org. matter (%)	≈ 56.0
- Ash (%)	≈ 44.0
- C (%)	≈ 27.3

- Heavy metals (mg/kg)	
Cd	≈ 2.7
Cu	≈ 402.5
Ni	≈ 58.0
Pb	≈ 159.5
Zn	≈ 1227.5
Hg	≈ 2.8
Cr	≈ 163.5

- Reactor → Bubbling Fluidized Bed (BFB)

- Bed of silica sand (300-500 µm)

- Catalysts (primary)

1) **olivine** $(Mg,Fe)_2SiO_4$

2) **alumina** $Al_2O_{(3-x)}(OH)_{2x}$

3) **dolomite** $CaMg(CO_3)_2$

- Gasifying agent (air and air-steam mixtures)